First measurements of Collins and Sivers asymmetries at COMPASS

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COMPASS is a fixed-target experiment on the SPS M2 beamline at CERN. Its ^{6}LiD target can be polarised both longitudinally and transversally with respect to the longitudinally polarised 160GeV/c μ^+ beam. Approximately 20% of the beam-time in 2002, 2003 and 2004 was spent in the transverse configuration, allowing the first measurement of both the Collins and Sivers asymmetries on a deuterium target. First results from the the transverse data of the COMPASS run in 2002 are reported here.

1. The Theoretical Background

The cross-sections for polarised deep inelastic scattering [1] of leptons on spin-1/2 hadrons can be expressed at leading twist as a function of three independent quark distribution functions: the unpolarised function $q(x)$, the longitudinally polarised "helicity" function $\Delta q(x)$ and the transversely polarised or "transversity" function $\Delta_T q(x)$. This latter function is chiral-odd and therefore decouples from inclusive DIS. It can however be measured in semi-inclusive DIS where it appears in combination with a chiral-odd fragmentation function, the Collins function $\Delta D_a^h(z, p_T^h)$, in an azimuthal single-spin asymmetry (SSA) in the hadronic end-product [2]. A similar asymmetry could however also arise from a modulation of the transverse momentum k_T of unpolarised quarks in a transversely polarised nucleon represented by the Sivers function, $\Delta_0^T q$ [3]. The Collins and Sivers effects can be disentangled in leptoproduction on a transversely polarised nucleon, since they exhibit a dependence on linearly independent kinematic variables.

The Collins hypothesis holds that the fragmentation function of a quark of flavour a in a hadron h can be written as [4]:

$$D_a^h(z, \mathbf{p_T^h}) = D_a^h(z, p_T^h) + \Delta D_a^h(z, p_T^h) \cdot sin\Phi_C \tag{1}$$

where $\mathbf{p_T^h}$ is the final hadron transverse momentum with respect to the quark direction – i.e. the virtual photon direction – and $z = E_h/(E_l - E_{l'})$ is the fraction of available energy carried by the hadron (E_h is the hadron energy, and E_l and $E_{l'}$ are the incoming and scattered lepton energies respectively). The angle Φ_C appearing in the fragmentation function is known as "Collins angle" and is conveniently defined in the system where the z-axis is the virtual photon direction and the x-z plane is the muon scattering plane as $\Phi_C = \Phi_h - \Phi_s'$, where Φ_h is the hadron azimuthal angle, and Φ_s' is the azimuthal angle of the transverse spin of the struck quark (nucleon). Since $\Phi_s' = \pi - \Phi_s$, where Φ_s is the azimuthal angle of the transverse spin of the initial quark (nucleon), the relation

$\Phi_C = \Phi_h + \Phi_s - \pi$ is also valid. The fragmentation function $\Delta D_a^h(z, p_T^h)$ couples to transverse spin distribution function $\Delta_T q(x)$ and gives rise to an SSA (denoted as A_{Coll}) dependent on the kinematic variables x, z and p_T^h.

Following the Sivers hypothesis, the difference in the probability of finding an unpolarised quark of transverse momentum $\mathbf{k_T}$ and $-\mathbf{k_T}$ inside a polarised nucleon can be written as [5]:

$$\mathrm{P}_{q/p^\uparrow}(x, \mathbf{k_T}) - \mathrm{P}_{q/p^\uparrow}(x, -\mathbf{k_T}) = \sin\Phi_S \; \Delta_0^T q(x, k_T^2) \tag{2}$$

where $\Phi_S = \Phi_k - \Phi_s$ is the azimuthal angle of the quark with respect to the nucleon transverse spin orientation. It has been recently demonstrated by theoretical arguments [6,7], that the SSA (denoted by A_{Siv}) coming from the coupling of the Sivers function with the unpolarised fragmentation function $D_a^h(z, p_T^h)$ can be observed at the leading twist from polarised semi-inclusive DIS.

2. The COMPASS Experiment

The COMPASS [4,8] experiment on the M2 beamline of the SPS accelerator at CERN makes use of a high energy, intense μ^+ beam naturally polarised by the pion-decay mechanism. The helicity of the beam is negative, and the polarisation lies at around 76% at a momentum of 160 GeV/c. The spill structure of the SPS in 2002 consisted of a 4.8 s burst containing approximately $2 \cdot 10^8$ muons followed by 11.4 s out-time. The luminosity of the beam was around $5 \cdot 10^{32}$ cm^{-2}s^{-1}. The spectrometer itself comprises two stages each equipped with a spectrometer magnet and detectors for tracking, energy determination and particle identification [9].

COMPASS uses the polarised target system of the SMC experiment which consists of two ^{6}LiD cells, each 60 cm long and with a radius of 1.5 cm located one after the other along the beam axis. In longitudinal running a 2.5 T field is maintained by a solenoid magnet, supplemented in transverse running by an orthogonal 0.5 T dipole field. The relaxation time of around 2000 hours of the dipole field is sufficient to allow the transverse measurement. The two target cells are always maintained with opposite polarisation. Transverse polarisations P of +/- 50 % are routinely reached; the dilution factor f of the target material is calculated to be around 0.38.

3. Analysis of the 2002 Data

Two periods of data with transverse target polarisation were taken in 2002. In order to compensate the different acceptances of the target cells, their polarity was flipped by microwave reversal halfway through each period. The counting rate asymmetry between these two sub-periods was then measured for each target-cell separately. The number of events in each of the two polarisation states (↑/↓) may be written as a function of the Collins (Sivers) angle as

$$N_{\uparrow\downarrow}(\Phi_{C/S}) = \alpha(\Phi_{C/S}) \cdot N_0 \left(1 \pm \epsilon_{C/S} \sin\Phi_{C/S}\right), \tag{3}$$

where ϵ is the amplitude of the experimental asymmetry and α is a function containing the acceptance of the apparatus. The angles are always calculated assuming the target

polarisation point up in the lab system. The "raw" amplitude ϵ is connected to the Collins (Sivers) asymmetry through the expression

$$\epsilon_C = A_{Coll} \cdot P_T \cdot f \cdot D_{NN} \qquad or \qquad \epsilon_S = A_{Siv} \cdot P_T \cdot f\,, \tag{4}$$

with D_{NN} is the spin transfer coefficient or "depolarisation factor". Indicating with y the fractional energy transfer from muon to virtual photon in the initial scattering process, D_{NN} may be calculated from the kinematics of each individual event through $D_{NN} = (1-y)/(1-y-y^2/2)$ in the case of the Collins effect. For the Sivers effect $D_{NN} = 1$, since this effect deals with unpolarised quarks.

In each period ϵ_C (ϵ_S) is fitted separately for the two target cells from the event flux with the two target orientations using the expression

$$\epsilon_{C/S} \sin \Phi_{C/S} = \frac{N_h^{\uparrow}(\Phi_{C/S}) - R \cdot N_h^{\downarrow}(\Phi_{C/S})}{N_h^{\uparrow}(\Phi_{C/S}) + R \cdot N_h^{\downarrow}(\Phi_{C/S})} \tag{5}$$

where $R = N_{h,tot}^{\uparrow}/N_{h,tot}^{\downarrow}$ is the ratio of the total number of events in the two target polarisation orientations.

The total sample collected in the 2002 transverse data-taking periods amounted to about 200 pb^{-1} in terms of integrated luminosity. Events were selected in which a primary vertex with identified beam and scattered muon and at least one outgoing hadron was found in one of the two target cells. A clean separation of muon and hadron samples was achieved by cuts on the amount of material traversed in the spectrometer. In addition, the kinematic cuts $Q^2 > 1(\mathrm{GeV}/c)^2$, $W > 5$ GeV/c^2 and $0.1 < y < 0.9$ were applied to the data to ensure a deep-inelastic sample above the region of the nuclear resonances and within the COMPASS trigger acceptance. The upper bound on y also served to keep radiative corrections small. The asymmetries were calculated for two different samples: both for all hadrons emerging from the primary vertex, and, a sub-sample of this, only for the most energetic or "leading" hadron in each event. The leading hadron was determined as the most energetic non-muonic particle of the primary vertex with an energy component $z > 0.25$ and a transverse momentum $p_T^h > 0.1$ GeV/c. When all the hadrons coming from the primary vertex were considered, the z cut was lowered to 0.20. The final data sample had average values $x = 0.034$, $y = 0.33$ and $Q^2 = 2.7$ $(\mathrm{GeV}/c)^2$. The average value for z and p_T^h are 0.44 and 0.51 GeV/c respectively for the leading hadron analysis, and 0.38 and 0.48 GeV/c in the all hadrons case.

The results of the asymmetries plotted against the kinematic variables x, z and p_T^h are shown in Fig. 1 for positive (full points) and negative (open points) hadrons, and for the analysis of leading (top plot) hadron and all hadrons (bottom plot).

Stability checks showed that the ratio of acceptances and efficiencies as a function of the Collins (Sivers) angle does not change between two spin orientations. Furthermore the results were stable when each target cell was split into two parts and the asymmetry calculated separately, and when the data was split into high and low hadron momenta. This leads to the conclusion that systematic effects are smaller than the statistical errors.

In these first measurements of transverse spin effects on a deuteron target, the Collins and Sivers asymmetries were found to be compatible with zero within the statistical accuracy of the data. A marginal indication of a Collins effect at large z for both positive and

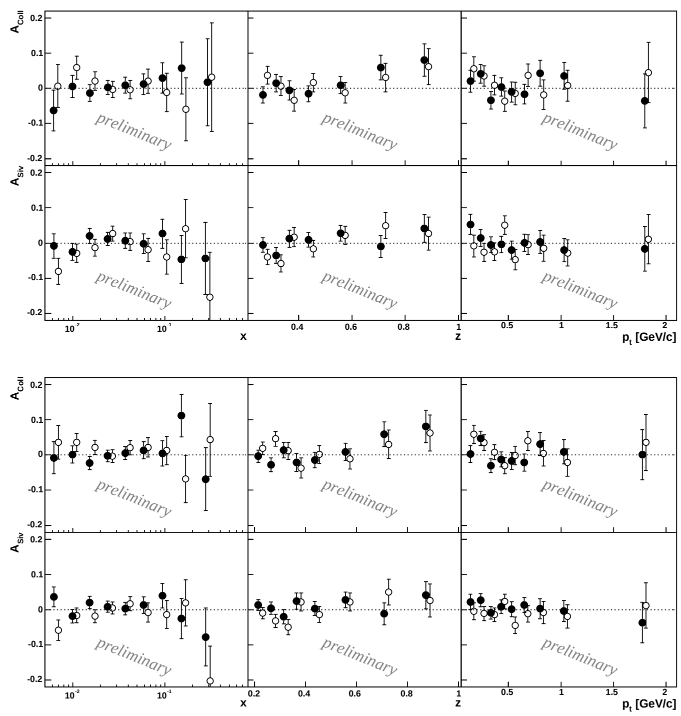

Figure 1. Collins and Sivers asymmetry for positive (full points) and negative (open points) hadrons as a function of x, z and p_T^h. Leading hadrons analysis on top canvas, all hadrons on bottom canvas.

negative charges is seen. Coupled with HERMES results on a proton target also reported at this conference, this may imply a negative neutron contribution to the asymmetries.

A sensitivity improvement of factor two is expected once the data from the 2003 and 2004 COMPASS runs have been analysed. From 2006 onwards, a target magnet with a significantly larger acceptance should increase the statistics at high x. Complementary measurements with a proton target are also planned.

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